Bio-Optical Response and Coupling with Physical Processes in the Lombok Strait Region

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LONG-TERM GOALS

Our overarching long term goal is to understand the coupling of bio-optical processes and properties with physical processes in ocean regions of strong physical forcing. Strong physical forcing can include several processes such as wind forcing, tidal forcing, and in the case of this project, flow through archipelagos.

In addition, we desire to understand the relationship between optical signatures and the components of the water column (e.g. sediments, phytoplankton and dissolved organic material) that create these signatures. Biological, chemical, geochemical, and geological processes contribute to these signatures.

OBJECTIVES

The primary goals of this study are to understand:

1. The three-dimensional distribution of inherent optical properties in the Philippine archipelago, a relatively unexplored region of the world ocean for which relatively little optical data exist.

2. The coupling of bio-optical properties with the physical processes that contribute to and result from the dynamics of flow through straits and steep topography.

3. Relationship between the surface expression of three-dimensional ocean processes and the interior processes.

4. The contribution of dissolved and particulate matter to in-water optical properties and their effect on ocean color remote sensing.

APPROACH

Our field approach to achieving the above objectives consistent of four observational components:

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1. Three-dimensional physical/bio-optical mapping is carried out in regions of the archipelago where strong physical dynamics are expected. Optical sensors are mounted on the UW-APL towed undulating vehicle for mapping 3-dimensional distributions of inherent optical properties that should respond to the physical processes of the straits. We deploy a Wetlabs ACS hyperspectral absorption/attenuation meter, a Wetlabs BB9 9-wavelength backscatter sensor, and fluorometers for the measurement of CDOM and chlorophyll.

2. Continuous nearsurface underway measurements of inherent optical properties are obtained from the ship's underway seawater flow system. These measurements include unfiltered and filtered absorption/attenuation measurements using either Wetlabs AC9 or ACS instruments, spectral backscatter, and particle size spectra with the LISST-100. Both this set of measurements and the following item are important for interpreting remotely sensed ocean color observations.

3. Continuous ship-based measurements of "on the water" hyperspectral remote sensing reflectance will be obtained with a Satlantic HyperSAS system. The HyperSAS provides high spatial and spectral resolution of remotely sensed remote sensing reflectance without atmospheric interference, which is key to linking in water optical properties distributions with remotely sensed optical signals.

4. Station based high resolution vertical profiles of physical, inherent optical, and radeiometric optical properties are obtained with a bio-optical profiler. These measurements are made in conjunction with CTD-rosette casts to provide verification and interpretation of the in situ towed observations and the remotely sensed apparent optical properties.

5. Provide support for continuous near-surface underway measurements and measurements from the CTD rosette of a subset of inherent optical properties during cruises we do not participate in.

WORK COMPLETED

The first of two intensive observational period (IOP) cruises of the Philippine Straits Dynamic Experiment (PHILEX) was carried out from February 7 to 27, 2008. The first IOP cruise was a collaborative effort with the towed vehicle efforts of Craig Lee (UW) and Mike Gregg (UW). The goal of the cruise was to observe processes that developed under the forcing of northern or northeasterly winds. Two of the surveys (Wind Jet 1 and Mindoro) were in the region of wind jets, one survey evaluated the role of an island in the center of the Mindoro Straits on the flow through the strait (Apo Reef), and a set of surveys were made near the southern tip of Mindoro (Figure 1).

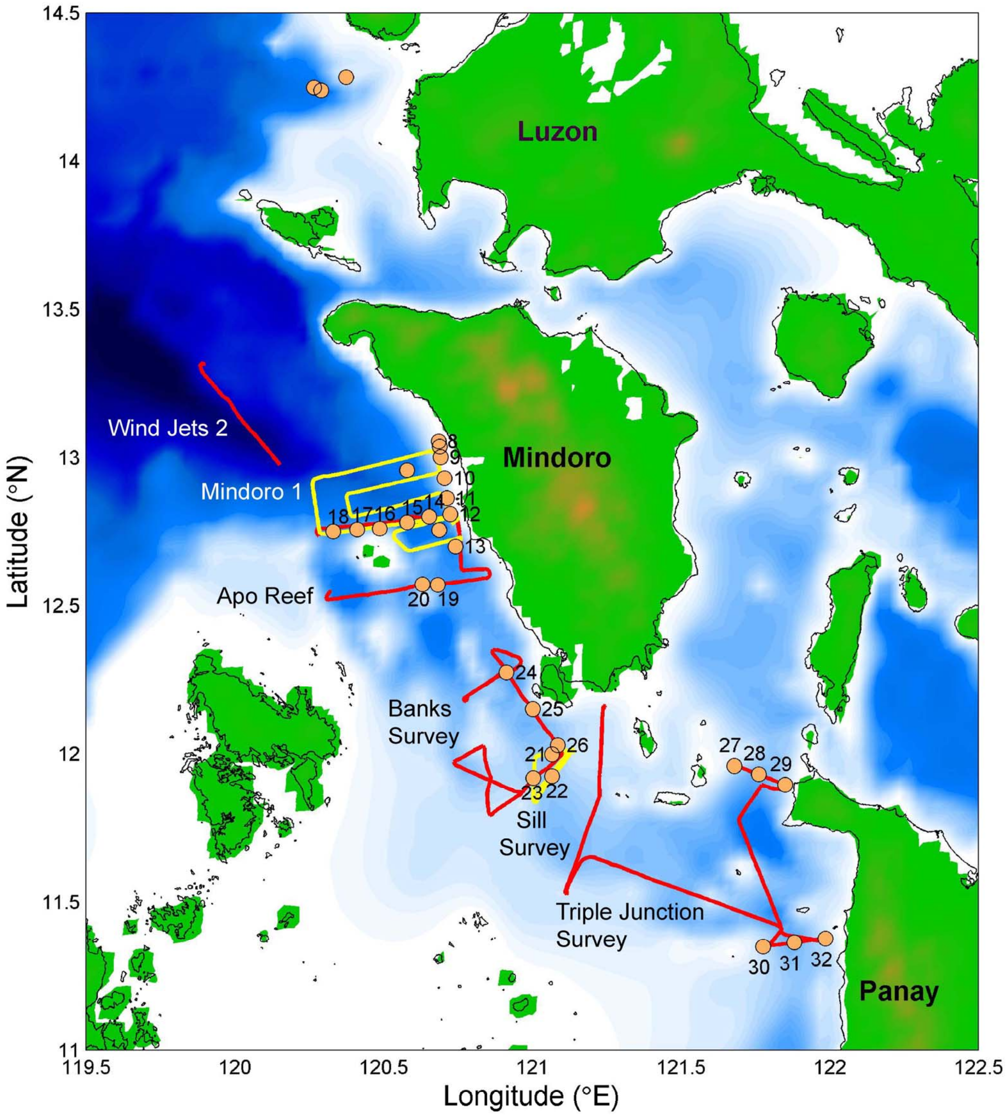

Figure 1. Map of the study region for first intensive observational period, February 7-27, 2008. The red and yellow lines indicate the path of Triaxus tows that included the ACS spectral absorption and attenuation measurements. The orange dots indicate the location of full bio-optical profiles.

RESULTS

Effects of Wind Jets

A survey along the western coast of Mindoro (stations 8-13 in Figure 1) examined the ocean response to a wind jet created by flow through mountain passes on Mindoro. Both physical and bio-optical variables appeared to respond to shear from the wind jet (Figure 2). Maximum particle concentration (indicated by c_p650 and $b_{bp}532$) occurred along the northern boundary of the wind jet. Not only was the particle concentration higher, but the particle size increased in this region (not shown). The profiles of salinity and $b_{bp}532$ indicate mixing down to 70 meters (station 10 in Figure 2). Whether this was due to local mixing or advection of mixed water from nearer the coast is uncertain at this time.

Because of the vertical mixing from the surface to 70m, these signals should be observable in remotely sensed ocean color as increased backscatter signatures.

Significant near-bottom resuspended particle layers were observed where the topography shallowed (stations 8 and 10). Optical backscatter in these layers was greater than 0.02 m^{-1} and the backscattering/scattering ratio was also high, consistent with the resuspension of mineral material from the bottom. We expect that this resuspension is related the interaction of the strong northward flow and the shallowing coastal bathymetry.

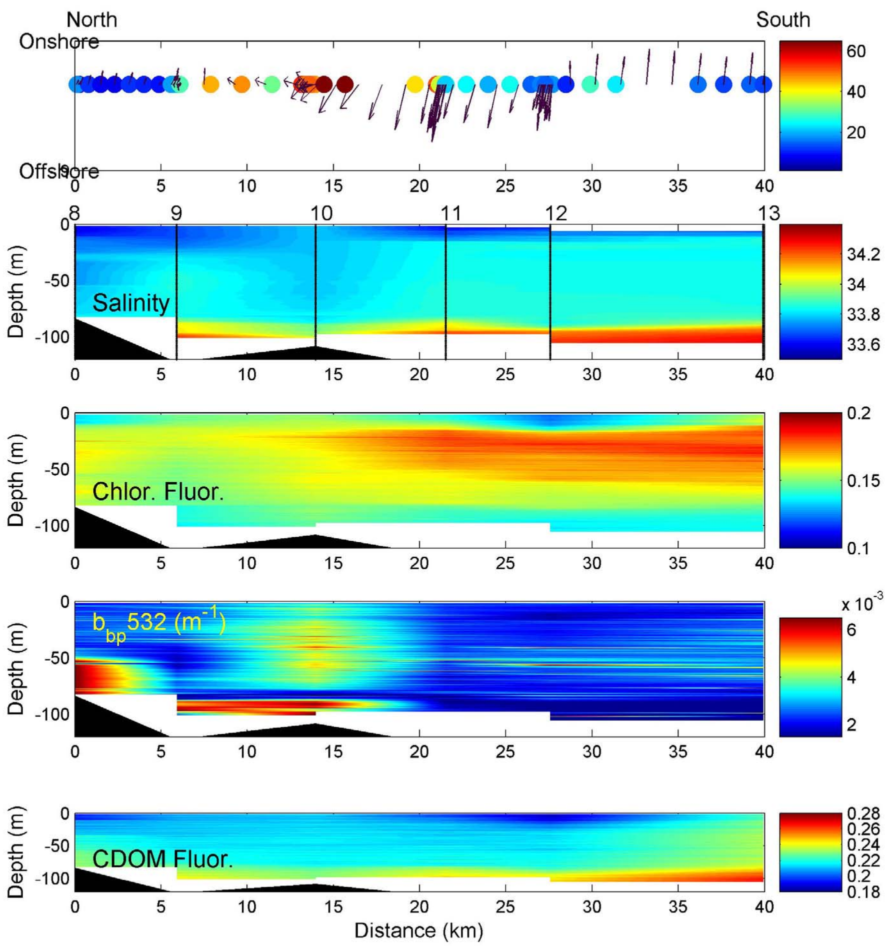

Figure 2.Bio-optical section along the west coast of Mindoro (stations 8-13 in Figure 1). The top panel shows c_p(650 nm) from the underway flowthrough system and wind vectors as measured from the ship. Color coding indicates the magnitude of c_p650. The vectors show the wind speed and direction (up is onshore, down is offshore). Station locations are indicated by the vertical black bars in the Salinity panel.

Junctions and Sills

Optical signatures are also generated in regions where there is flow around the corners of islands, flows are converging, and/or there is significant coastal topography that interacts with the flow. These types of features have been observed in remotely sensed ocean color, but not understood from the 3-

dimensional perspective. A Triaxus towed vehicle survey of the region between Mindoro and Panay where there are 3 sills and potentially convergent flow from the south, east and northwest (Figure 3). In contrast to the wind jet example, described above, the particle distributions (c_{660}) and chlorophyll are well correlated, indicating that the particle concentration is dominated by biological processes in this region. Secondly, the chlorophyll/particle maximum for most of the stratified region underlies the surface mixed layer, where nutrients become available in the pycnocline. And thirdly, where the highest nearsurface chlorophyll and particle concentrations are observed along the northwestern portion of the survey near the Mindoro coast, surface mixed layer depth is deep (40-60 meters) and salinity is higher than in adjacent lower chlorophyll waters..

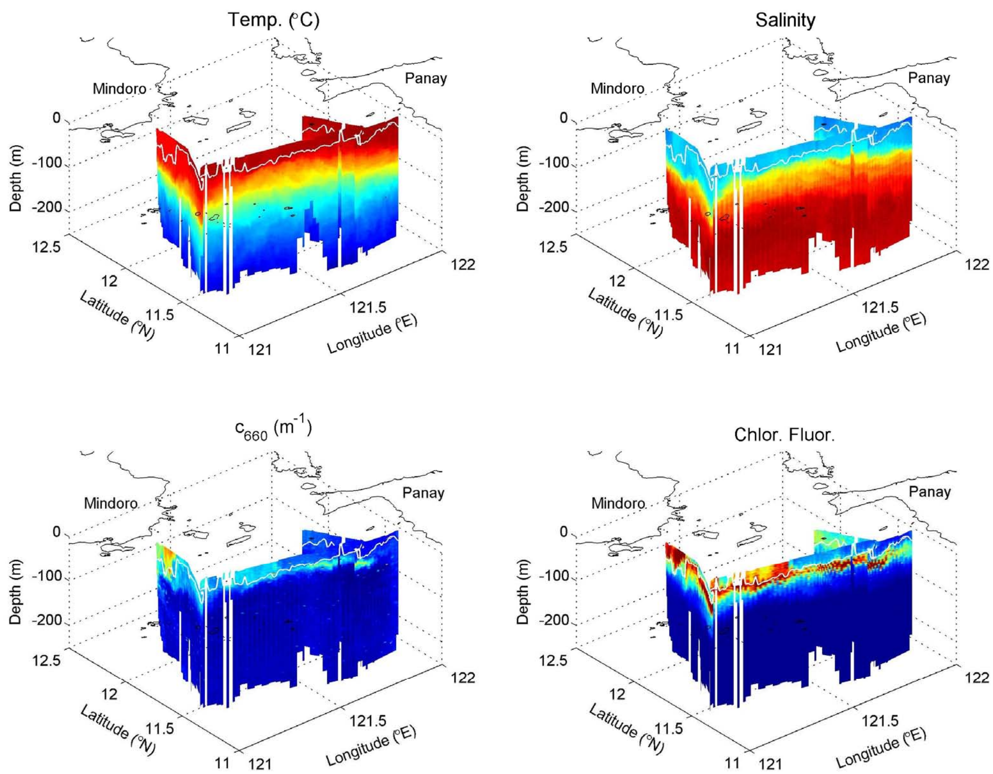

Figure 3. Curtain plots of temperature, salinity, beam attenuation at 660 nm (c_p660), and chlorophyll fluorescence from a survey between the southern tip of Mindoro and the northern tip of Panay (see Figure 1). The depth of the mixed layer (defined as the region where sigma-theta changes by less than 0.05 kg/m^3) is indicated by the solid white line (most clearly seen in temperature plot).

The near-surface expression of the feature south of Mindoro shows that the high chlorophyll, high particle concentration (c_p652) water extended to the southwest (Figure 4). The lower wavelength-dependent slope of c_p, gamma-c, in the high chlorophyll region indicates larger particles either due to larger individual cells or formation of cell chains or aggregates. Satellite imagery often indicates higher chlorophyll and suspended particulate matter in this region. We hypothesize that flow through the strait immediately south of Mindoro results in both uplifting of isopycnals, and hence nutrient containing water, as it flows over the sill and the shallow flow also induces vertical mixing of the

upper layer and then stabilizes as it flows southwest of the sill, resulting in the increased phytoplankton populations. We intend to investigate this process further during the 2009 IOP cruise.

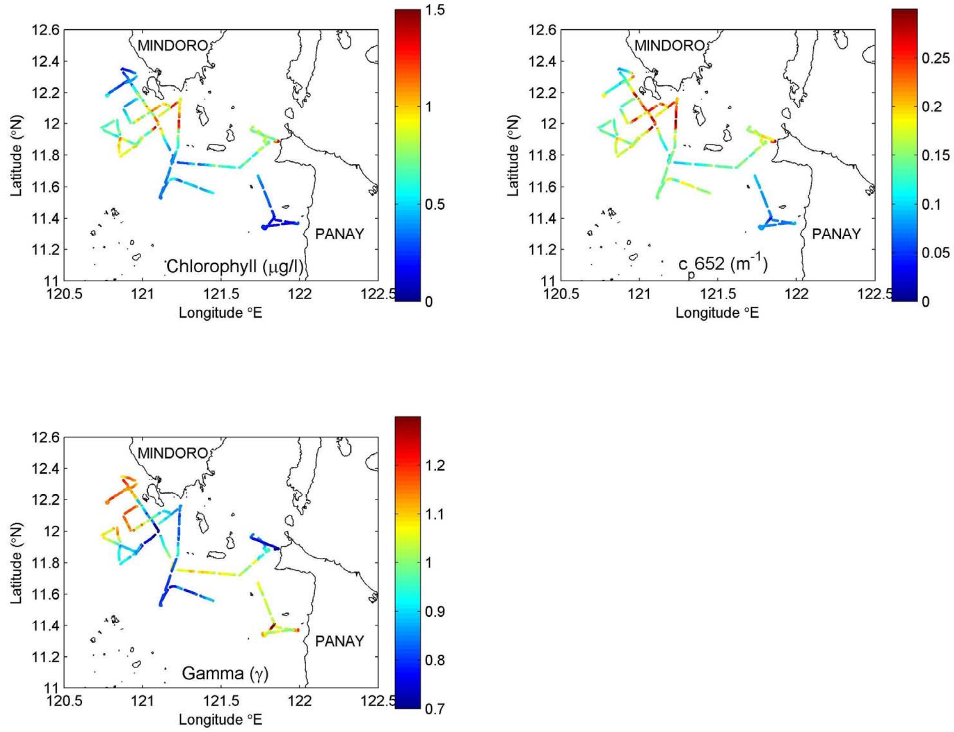

Figure 4. Near-surface underway distribution of chlorophyll concentration, beam attenuation (c_p652) and the gamma-c (slope of beam attenuation coefficient as a function wavelength). Low gamma values indicate larger particle size and larger gamma values indicate smaller particle size distribution.

Major conclusions:

1. The background distributions of bio-optical variables in the Philippine straits were similar to what is expected in a tropical, thermally stratified ocean. The primary source of optical signature originated from subsurface phytoplankton populations within the pycnocline where there is sufficient light and nutrients to sustain the population.

2. Wind jets cause localized effects on both the physical and bio-optical structure. Low salinity, high particulate region observed off Mindoro was several kilometers wide and extended to about 70 m depth. This feature was associated with the northern shear boundary of the wind jet.

3. Flow through a narrow strait and its associated sill resulted in the increased salinity and vertical mixing. Increased chlorophyll was associated with this feature and apparently was advected toward the southwest, consistent with features that have been observed in remotely sensed ocean color images.

4. Modification of the bio-optical structure can be caused by freshwater inputs, flow past sea-mounts, flow over shallow topography, coastal regions where the flow and mixing are modified by the coastal boundary, or wind jets that cause local stirring of the water column.

IMPACT/APPLICATIONS

The observations from this effort will facilitate interpretation of physical processes and structure from remotely sensed ocean color in the region of the Philippine archipelago. The results will also be useful for assimilation and verification of numerical modeling efforts that include inherent optical properties, particle dynamics and transformations that occur in and around island archipelagos.

RELATED PROJECTS

We have collaborations related to this program with the following ONR principal investigators:

Mr. Robert Arnone	NRL-SSC	http://www7333.nrlssc.navy.mil/
Dr. Arnold Gordon	Columbia University – Lamont Dougherty Earth Observatory	http://www.ldeo.columbia.edu/~agordon/
Dr. Michael Gregg	University of Washington	http://opd.apl.washington.edu/scistaff/bios/gregg/gregghome.html
Dr. Craig Lee	University of Washington	http://iop.apl.washington.edu/
Dr. Pierre Flament	University of Hawaii	http://www.satlab.hawaii.edu/users/pflament/